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Touch screen use on flight simulator Instructor Operator Stations

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THESIS

TOUCH SCREEN USE ON FLIGHT SIMULATOR INSTRUCTOR/OPERATOR STATIONS

by

Alan Andrew Vazquez

September 1990

Thesis Advisor: Judith H.Lind

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The goal of this study was to aid designers in selecting the best data input device for the design of Instructor/Operator Stations (IOSs). A literature review of touch screen, mouse, and trackball technologies is provided. IOS users' experience level, frequency of touch screen interaction, and familiarity with touch screen, mouse, and trackball devices are provided, along with data on the tasks performed, required accuracy, parallax, arm fatigue, and feelings toward touch screen use. It is concluded that, although touch screens are being used by persons with too much experience and for tasks reported in the literature to be inappropriate, results are generally satisfactory. However, it is recommended that input devices should be matched with the tasks performed.

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Touch Screen Use on Flight Simulator Instructor/Operator Stations

by

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Lieutenant, United States Navy
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Submitted in partial fulfillment
of the requirements for the degree of

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ABSTRACT

The goal of this study was to aid designers in selecting the best data input device for the design of Instructor/Operator Stations (IOSs). A literature review of touch screen, mouse, and trackball technologies is provided. IOS users were surveyed to evaluate the use of touch screens with several military flight simulators. IOS users' experience level, frequency of touch screen interaction, and familiarity with touch screen, mouse, and trackball devices are provided, along with data on the tasks performed, required accuracy, parallax, arm fatigue, and feelings toward touch screen use. It is concluded that, although touch screens are being used by persons with too much experience and for tasks reported in the literature to be inappropriate, results are generally satisfactory. However, it is recommended that input devices should be matched with the tasks performed.

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I. INTRODUCTION

A. BACKGROUND

Automated training systems have become an integral part of the military as a result of demonstrated cost effectiveness and high quality. It is anticipated that the importance of these systems will increase in the face of military budget cutbacks and the need to "do more with less". Consequently, the Navy continually will need to seek improvements in the design of its training systems. One area of automated training systems in need of attention is the Instructor/Operator Station (IOS).

The IOS consists of the displays and controls used by the instructor to interact with the training system.
The IOS derives its name from the fact that many automated training devices require an instructor or operator to control the training session and impart expertise to the trainee. An example is an automated flight trainer where a student trainee "flies" the aircraft while an instructor monitors the training session.

For a system designed with an IOS, one or more individuals perform all input tasks necessary to create the desired "environment" under which flight training is to be conducted. Tasks such as aircraft and target positioning, weapons and

fuel loading, practicing normal and emergency procedures, and changing weather conditions are examples that are common to many flight simulators. However, the methods used for data input via the IOS can differ significantly.

The Naval Training Systems Center (NTSC) in Orlando, Florida, is in the process of reviewing several modern automated training devices in order to gather information for improving the design of the IOS [Ref. 1]. NTSC has focused its attention on methods by which instructors can input data and commands to the system. It is apparent to NTSC that an increasing number of systems are employing touch screen technology for all or part of the instructor's interface with various systems. System developers at NTSC have questioned the input device selection process for military training devices. [Ref. 2]

The lack of information regarding how best to make selections places system developers in a situation in which they must continually "reinvent the wheel." Each time a new training system is developed, similar issues are addressed with respect to input device selection. There exists very little data as to which input device is best suited to perform the tasks required by a given system.

Although touch screen implementation may appear to be a logical choice for user inputs, a definitive guideline for selecting input devices is unavailable. A comprehensive review of alternative input techniques is needed in order to

determine which input device is best suited for a particluar IOS. Operator performance while using a mouse or a trackball should be compared with touch screen performance prior to making a final decision. This information will lead to an improved design process, resulting in more effective training systems.

B. MILITARY FLIGHT SIMULATORS

Several Air Force, Navy, and Marine Corps flight simulators used for training are located at Luke Air Force Base, Phoenix, Arizona (F-15E and F-16C aircraft), Lemoore Naval Air Station, California (A-7E), Marine Corps Air Station, Yuma, Arizona (AV-8B), and Marine Corps Air Station, El Toro, California (F/A-18). These sites are representative of all simulators located in the Western United States which use touch screens as input devices. All of these trainers are operated from a console where the instructor and operator perform the various data entry tasks needed to conduct a training flight in the simulator.

The F-16C weapon systems trainer (WST) IOS uses an oversized optical (infrared) touch screen monitor to perform data input. All data entry is done through one of two identical monitors. Each monitor sits on a desk, surrounded by a small console with dummy aircraft gauges and a monitor which allows the instructor to call up any one of the pilot's head-up display screens. The console uses only two screens.

All console components are visible and easily reachable from a sitting position.

The F-15E WST IOS consists of a large console (Figure 1) which wraps approximately 180 degrees around the instructor and the operator. Displays are located around the console stretching from desktop level to roughly 6 feet above the desk. A total of 17 screens are located in this IOS. Two of these screens are resistive membrane touch screens used for high-level menu selection. While there is some redundancy of screens, most of them display unique information.

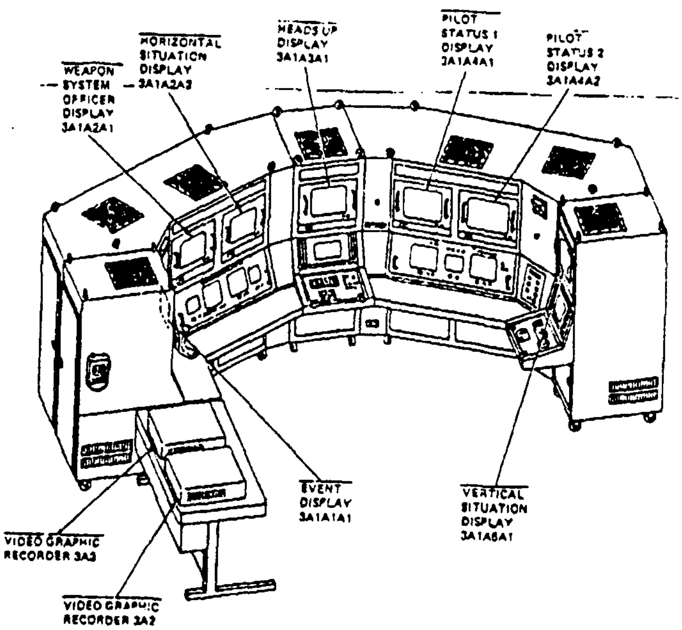

Figure 1. F-15E Simulator Instructor/Operator Station

The A-7E WST IOS consists of one panel containing one monitor screen, a combination of dedicated keys, and a traditional keyboard for data input. Three redundant

capacitive touch screens are located beside the display and control panel. These screens were added to the original IOS to perform weapons loading tasks through menu selections.

The AV-8B WST IOS (Figure 2) is designed in an "L" shape with instructor input terminals on the right and general display monitors directly in front of the instructor. System setup is accomplished using dedicated function keys. One infrared touch screen is located on the instructor's right and is used for system control via menu selection.

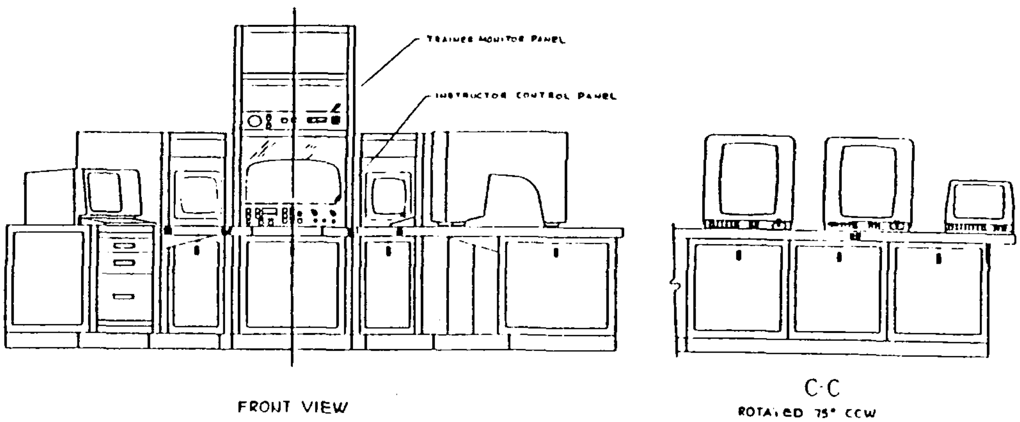

Figure 2. AV-8B Simulator Instructor/Operator Station

The F/A-18 WST IOS is also designed in an "L" shape. Two capacitance-type touch screens are located on either end of the control panel for system control via menu selection. Dedicated keys located adjacent to the touch screens can

perform the same functions and may be used instead of the touch screens. The center area of the control panel contains several multi-purpose monitors for training session overview.

C. RELATED STUDIES

An extensive literature review on alternative input methodology provided mixed results on the relative value of the mouse, trackball, and touch screen. Each device is designed to optimize performance of a specific type of task or group of tasks. For instance, as Pickering [Ref. 3: pp. 249-269] notes, no single type of touch screen technology is able to perform all the different input tasks well. "All commercially available techniques have concentrated on one particular sensing method, for market reasons, and have optimized that method to meet the detection requirements."

Similar design limitations affect the mouse and trackball. Reports and articles on the subject of alternative input devices suggest that market forces (which equate to customer preference) drive the development of the devices. Accordingly, each of the devices reflects a particular slice of the market and may or may not be appropriate for any given application.

For example, Karat, [Ref. 4:pp. 73-78] suggests that the actual selection of an input device for a particular system is technology dependent. Card [Ref. 4:p. 76] found the mouse to be the best device for target selection while users performed

poorly using a mouse in an entirely menu-driven system. Touch screen was found to be the preferred device for the all menu-driven systems.

These results do not translate easily into information applicable to a given user with a given set of tasks to perform. Eckhouse [Ref. 5:p. 128] further clouds the issue when he concludes that the mouse is quite natural for screen-oriented applications and that the touch screen is most useful for high-end systems (commercial and military) and for use on information kiosks. Furthermore, Eckhouse notes that the mouse and trackball have considerably better resolution than the touch screen and that the touch screen has no equivalent to the pushbuttons found on the mouse and trackball. Rosenthal [Ref. 6:p. 90] claims that most experts believe touch screens are best suited for specialized operations such as factory control and telephone operator assistance.

While opinions on the relative value of the three kinds of devices is mixed, some degree of consensus exists concerning which are best suited for general input activities. This consensus provides simple guidelines to assist designers and developers in specifying input requirements for a given system.

Six types of abstract input tasks are proposed by Foley [Ref. 7:pp. 13-48] to allow for a general ranking of input devices. These tasks are termed select, position, path, text entry, quantify, and orient. Quantify and orient tasks do

not apply to this comparison of touch screen, mouse, and trackball devices. Text entry is the process of a user specifying a sequence of symbols, such as composing a filename. This task is applicable to the comparison of the three input devices, but to a lesser extent than select, position, and path, due to the nature of the devices at hand. Selection is the act of choosing an item from a set of alternatives. Menu selection is a common example of this type of task. Positioning requires the user to specify a point in a space defined by a particular application. An example of this task is placement of the cursor on a specific spot on an application screen. The path input task is performed when the user specifies a direction in a space defined by a particular application. The path input task permits curves to be drawn by the user. This is basically the same task as positioning, however direction is expressed rather than a single point. Table 1 illustrates generally-accepted preferences for the three devices, for use in performing selection, positioning, path, and text entry tasks.

TABLE 1. BEST INPUT DEVICES FOR THE PERFORMANCE OF FOUR GENERIC TASKS. Input devices are listed in order of preference. [Ref. 8:pp. 108-109]

Task	Preferred Input Device
Selection	Touch Screen, Mouse, Trackball
Positioning	Mouse/Trackball, Touch Screen
Path	Mouse, Trackball, Touch Screen
Text Entry	Mouse, Touch Screen, Trackball

D. GOAL AND OBJECTIVES

The goal of this study is to provide NTSC with information that may be used in deciding what type of input device is best suited for particular input tasks related to the IOS. Several objectives have been met to achieve this goal.

First, a comprehensive literature review was completed in order to determine a consenus as to what type of input devices are best suited for abstract input tasks (Table 1). Second, a survey was designed and administered to instructors and operators of several automated training systems. The survey has provided a means for comparing the types of input tasks currently carried out using IOS touch screens with the generally-accepted preferences listed in Table 1. Finally, conclusions and recommendations concerning the relationship between survey results and literature consenus are made based on the collected data.

E. SCOPE

This study reviews user performance and preferences related only to IOS computer inputs of three hardware devices: a mouse, trackball, and touch screen. Emphasis is on the use of these devices for automated training systems. It is not the intent of this study to determine the overall superiority of one input device over any other.

Those systems not designed with an IOS were not considered for this study due to their distributed, and therefore inaccessible, nature. Moreover, there are more similarities among instructors and operators who are trained to work with similar systems (such as flight simulators) than among those trained to use different systems. Finally, NTSC has a high degree of interest in the IOS, which is perhaps best exemplified in military flight simulators.

II. TOUCH SCREEN, MOUSE, AND TRACKBALL TECHNOLOGIES

A. BACKGROUND

The human-computer interface in the past has relied primarily on the keyboard as the means by which the user communicates with the computer. While the keyboard is still the predominant input device for commands and text, developments in software and hardware have led to greater system capabilities requiring the ability to "point" to a given target or selection on the screen. Programs requiring these capabilities include graphics, tracking, and computer-aided design. Pointing can be accomplished directly on-screen or with the use of off-screen control devices. Touch screen technology uses on-screen direct pointing, while the mouse and trackball are examples of off-screen indirect pointing devices.

There has been great emphasis on creating an easier-to-use environment to help bridge the gap between the rapidly expanding technologies behind new computer systems and naive users who must learn increasingly complex tasks in order to interface with these new computer systems. Manufacturers have moved toward simpler communication layouts, on-screen pointing capability, graphical interfaces, and menu-driven selection

schemes. These trends have, in turn, led to the development of improved alternative input devices from which to choose.

A problem arises when considering the various options for alternative means of input. Which input device or devices should be used with a particular system? Numerous studies have examined this issue. However, as discussed in Chapter I, the results of these studies are not widely applicable. An appropriate input device for one system may or may not be desirable, or even feasible, for another system. Reasons for the lack of widely applicable data derived from these studies includes the use of specific, limited subject groups using specific software on specific hardware. Accordingly, the results apply only to the specific situations studied.

Since specific findings cannot reliably be applied to other situations, it is necessary to make use of general guidelines for input device selection rather than using formulas or recipe-type instructions. The prospective buyer of a new system faces a choice between conducting extensive studies independently or using generally-applicable guidelines to aid in the process of selecting input devices.

The touch screen, mouse, and trackball have all evolved in an attempt to keep pace with the ever-increasing demand for a satisfactory user-computer interface. Each device is different from the others, and models may also differ within a given device family. The following sections provide data on the current status of these three types of input devices.

B. TOUCH SCREEN TECHNOLOGY

Touch screens are meant to be easily operated by users without regard for each one's level of computer literacy. Touch screen operation is described by Kalb [Ref. 9:p. 52] as follows:

> Users input information into the computer merely by touching the portion of the screen representing the desired function. At the point of touch, the screen's controller detects a change in state, determines the X-Y coordinates, and sends this information to the processor for interpretation.

Touch screen technology makes use of several implementation schemes, each based on a different method by which the computer system senses the user's touch on the screen. System developers must consider each available type of touch screen implementation and its advantages and disadvantages, in addition to other design options. Four touch screen sensing methods currently in wide use are: resistive membrane, capacitance sensing, acoustic sensing, and optical sensing.

1. Resistive Membrane Sensing

Resistive membrane technology (Figure 3) employs two transparent sheets (membranes) with an electrode grid sandwiched between them. The combined sheets form an overlay which is applied to the face of a monitor. When the overlay is touched, the membranes come into contact with one another causing the electrodes to complete a circuit. The location of

the closed contact represents a location on the face of the screen. [Ref. 12:p. 135]

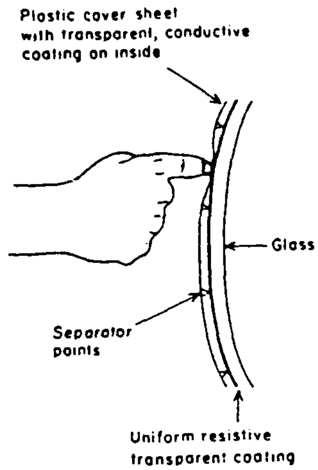

Figure 3. Resistive Membrane Screen [Ref. 3:p. 257]

This implementation offers the advantage of relatively high accuracy since firm pressure is required to produce a "hit" and because the area of contact is averaged to help pinpoint screen locations. Disadvantages of the resistive membrane implementation are that the membrane overlay is difficult to secure properly to the monitor screen and that the membrane sheets tend to be frail. Damage from scratches, punctures, coffee spills, and the like are hazardous to this type of touch screen. As a result, the resistive membrane touch screen is generally not recommended for public or industrial applications. [Ref. 11:p. 140]

2. Capacitance Sensing

Capacitance touch screens (Figure 4) use a thin metallic conductive coating on the outside of the screen to sense a touch. This type of surface has the advantages of relative durability and optical transparency, compared to other touch screen implementations. [Ref. 11:p. 141]

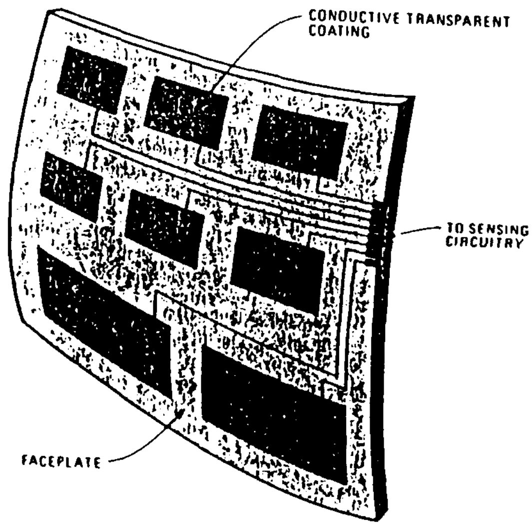

Figure 4. Capacitance Sensing Screen [Ref. 11:p. 142]

One disadvantage of this technique is that a conductive stylus (such as the human finger) is required; the touch of an ordinary pencil or a glove is not recognized. A further disadvantage of this design is that it needs to be adjusted for changes in ambient conditions such as temperature and humidity. [Ref. 11:p. 141]

3. Acoustic Sensing

Acoustic sensing touch screen (Figure 5) technology employs a series of piezo-electric transducers placed around the perimeter of a screen overlay to create acoustic surface waves along the X and Y axes of the screen. A touch is sensed by locating the point at which the waves are interrupted by the stylus or finger. [Ref. 11:p. 141]

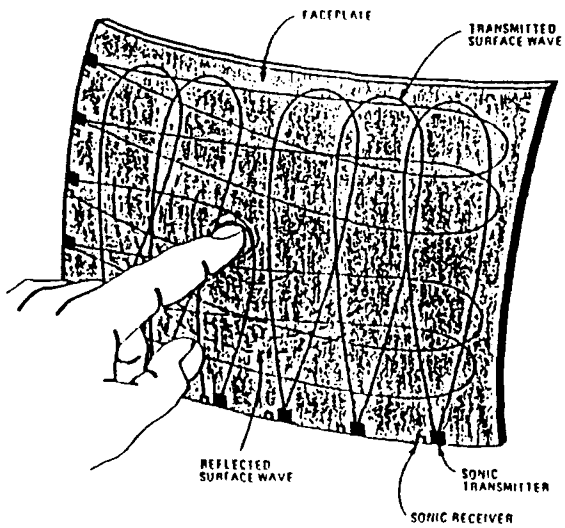

Figure 5. Acoustic Sensing Screen [Ref. 11:p. 143]

An advantage of this implementation is that it may be used for sophisticated applications because specific touch zones are programmable. However, this ability is limited in practical terms to about 1/2 inch of spacing between contact points. Higher resolution is achieved by placing the transducers closer together, which increases the sensitivity to particles of dust and dirt and often requires the use of

trained operators in order to keep the screen clean. [Ref. 11:p. 141]

4. Optical Sensing

Optical touch screens (Figure 6) use rows of light-emitting diodes (LEDs) around the periphery of the screen, creating a grid of infrared light. These are often referred to as infrared or IR touch screens. One advantage of this type of screen is that relatively high resolution is possible, in comparison to other touch sensing designs. In addition, the operator can define the size and shape of touch-active areas (from the entire screen to as small as 1/20 inch), the screens are reliable in public and industrial environments, and there is no overlay to contend with. [Ref. 11:p. 142]

As is the case with all other touch screen implementations, optical screens are not without disadvantages. The greatest problem is with parallax, caused by straight beams of light emanating from the peripheral LEDs across a curved screen surface. This phenomenon causes the beam to be close to the screen in the center, but farther away at the edges, resulting in decreased accuracy when working near the edges of the screen. [Ref. 11:pp. 142]

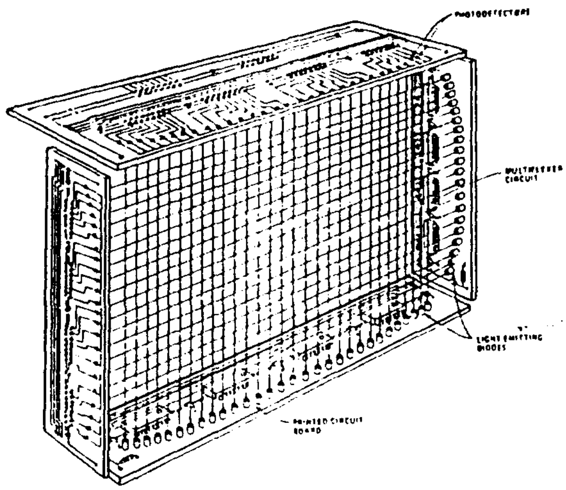

Figure 6. Optical (IR) Sensing Screen [Ref. 11:p. 144]

5. Comparison of Sensing Methods

Table 2 lists several attributes (advantageous and disadvantageous) of each of the four touch screen sensing methods: resistive membrane, capacitive, acoustic, and optical. Each of the four touch screen technologies is addressed according to the attributes listed. Information noted here provides a starting point from which a system developer can gather additional data about the various techniques.

TABLE 2. COMPARISON OF TOUCH SCREEN SENSING METHODS. [Ref. 12:p. 135]

	Touch Sensing Method			
Attributes	Resistive	Capacitive	Acoustic	Optical
Resolution	Pixel	1/2"	1/4"	1/4"
Inadvertent Activation	Less likely	No	Sensitive	Sensitive
Software Configurable	Yes	No	Yes	Yes
Touch With	Anything	Finger only	Anything	Anything
Susceptible To	Mis-alignment	Temperature, Humidity	Dirt, Scratches	Parallax

Table 3 illustrates which specific touch screen sensing methods are recommended to perform the abstract input tasks described in Table 1. Sensing methods are listed in order of ability to perform the tasks. The absence of a sensing method from the list indicates that it is not recommended for the given task. As may be observed, no single touch screen sensing implementation can perform all of these input tasks adequately, adding to the complexity of selecting among alternative input devices.

TABLE 3. USE OF TOUCH SCREEN SENSING METHODS FOR PERFORMING GENERAL INPUT TASKS. [Ref. 3:p. 267]

Task	Best Sensing Method
Selection	Resistive, Acoustic, Capacitive, Optical
Positioning	Optical, Capacitive, Resistive
Path	Optical, Resistive
Text Entry	Resistive, Acoustic, Capacitive

6. Touch Screen Advantages and Disadvantages

Overall, while individual touch screen implementations differ, there is agreement as to the advantages, disadvantages, and best uses for touch screens in a general sense. The advantages of a touch screen include ease of use, minimum space requirements (since it is an on-screen input device), and general suitability for menu-driven systems.

One disadvantage of touch screens is that accuracy is limited by the size of the finger or stylus being used to point and touch, making them incompatible with systems requiring highly accurate pointing and with screens that are crowded with functions. Another disadvantage is that they are not generally offered as standard equipment by many large companies, leading to reluctance by software manufacturers to invest in compatible software development. [Ref. 9:p. 53]

Still another disadvantage of touch screens is arm fatigue. While the simplicity of raising one's arm to touch the screen directly is seen as an advantage for these systems, doing so for long periods of time can become tiring and uncomfortable for the user. [Ref. 13:p. 40]

7. Best Uses for Touch Screens

The generally-accepted best uses for touch screens capitalize on their advantages. Alper [Ref. 14:p. 38] views the optimal application of touch screens as being in environments where computer literacy is low and rapid interaction with the system is required. Rosenthal [Ref. 6:p. 90] claims that "most experts still see this technology as best suited for specialized applications such as factory control or operator assistance." Guterman [Ref. 15:p. 13] finds viability for specialized touch screen applications in industrial process control and process automation. Ease of

industrial process control and process automation. Ease of use and minimum space requirements are often high priorities in these environments.

Eckhouse [Ref. 5:p. 128] proposes that touch screens are best suited for high-end commercial and military systems and for use on information kiosks. Ease of use for inexperienced users is often viewed as a top priority of such systems. Karat [Ref. 4:p. 73] found the touch screen to be the single most preferred device for menu-driven systems, because they take advantage of all of the best features of touch screens.

C. MOUSE TECHNOLOGY

The mouse (Figure 7) moves along a desktop or other surface and sends positioning signals (relative to the screen) to the processor. Mice can be either mechanical or optical. Both types are roughly the size of a deck of playing cards and each has a wire that connects it to the processing unit.

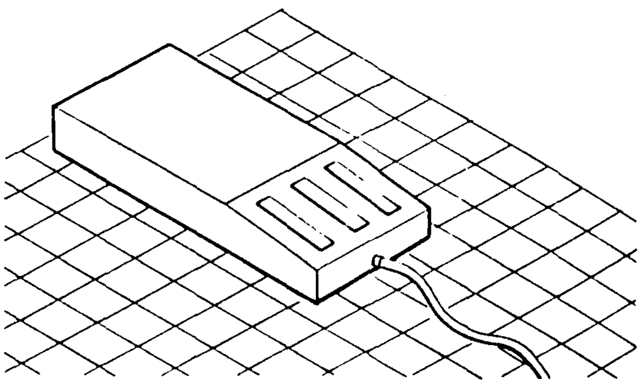

Figure 7. Mouse [Ref. 16:p. 214]

Perhaps the most common type of mouse is the mechanical mouse which uses potentiometers to sense the movement of a ball located underneath the unit. The optical mouse operates similarly; however, optical photosensors are located beneath the unit and "see" the relative movement over a surface rather than "feel" movement as the mechanical mouse does. Both types of mice translate relative movement of the device into electrical signals for interpretation and both function in essentially the same manner. [Ref. 17:p. 228]

1. Mouse Advantages and Disadvantages

Brown [Ref. 12:p. 139] cites several advantages of the mouse:

> A mouse provides accurate fine resolution cursor positioning and quick movement across long screen distances. It also minimizes arm fatigue because it allows the desktop to support the weight of the user's arm. Furthermore, the mouse may have one or more buttons on top of the unit for acting upon an object that has been pointed to on the screen. The mouse is quite compatible with visual interfaces and graphical manipulation.

Most mice have two or three buttons that allow for option selection as well as other operations. For example, the mouse can be used to relocate an object on the screen by placing the cursor at that location ("pointing to it"), pressing a button to "capture" the object, "dragging" the object to the new location, and releasing the button to "release" the object. This design characteristic makes the mouse excellent for positioning tasks and highly compatible

with graphics-oriented applications. Rosch [Ref. 17:p. 228] describes other mouse advantages, plus one disadvantage:

> Mice are inexpensive and familiar to most PC users. They are the most widely supported input device in terms of both hardware and software. Another point is that the higher the resolution, the faster the scroll, which makes pinpoint operations difficult.

The fact that the mouse is an off-screen indirect pointing device can affect a decision about its best use because of the requirement for desktop operating space. About 1 square foot of desktop space is required to operate a mouse [Ref. 12:p. 140]. The trackball, which is stationary, requires little desktop space and the touch screen requires none. As a result, space-critical applications may not be able to support mouse operations.

Another disadvantage is that the mouse requires better hand-eye coordination than a touch screen. With respect to menu selection, Karat [Ref. 4:p. 87] claims, "Touch selection is a highly automated skill for most humans, while other techniques are less well learned."

Mouse input requires an intermediate step between making a choice and indicating a choice. That is, the user must recall how to indicate the desired choice to the system. Direct pointing, as in touch screen operation, does not require this step. Karat [Ref. 4] also indicates that this intermediate step becomes more well learned over time, but

that experience will not overcome the advantage given to direct pointing.

2. Best Uses for the Mouse

The mouse is considered best suited for highly interactive graphical interfaces that require accurate pointing [Ref. 12:p. 139]. Such applications are more complex than simple selection of menu items. Positioning of an object on the screen or dragging an object from one screen location to another are examples of tasks which are performed easily using a mouse. The path task, defined in Chapter I, is also well suited for mouse operations.

D. TRACKBALL TECHNOLOGY

The trackball (Figure 8) is a ball about 2 to 5 inches in diameter that can be rotated within a fixed housing to move a cursor or other on-screen object [Ref. 12:p. 150]. "The trackball is basically a mouse on its back." [Ref. 18:p. 21] Operation of the trackball requires that the ball be rolled by hand, as the housing remains stationary. This highlights the most fundamental difference between the mouse and the trackball. The mouse requires the operator to move the entire mouse unit around on a desktop to indicate relative object movement on a screen. The trackball operator simply rolls the ball while the unit remains stationary, eliminating the need for repositioning. Rosch [Ref. 17:p. 229] describes the trackball as looking like a "cue ball set into a base."

Like the mouse, the trackball provides off-screen indirect cursor manipulation relative to the movement of the ball. The trackball may be a separate unit with a wire connecting it to the processor, or it may be built directly into a keyboard or an operator's console.

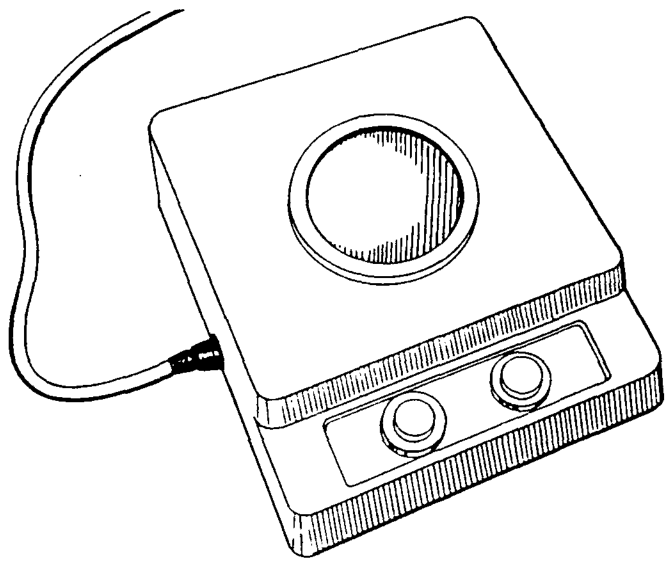

Figure 8. Trackball [Ref. 16:p. 213]

1. Trackball Advantages and Disadvantages

For the most part, the trackball and mouse provide similar capabilities for information input. This is primarily due to their similar designs and functions. However, trackballs are considered individually because they hold certain advantages over the mouse.

Perhaps the greatest advantage of the trackball over all other alternative input devices is its minimal space

requirement. Obviously, on a system where space is critical, the trackball receives higher consideration than for a system where there is no space restriction.

Another trackball advantage is its ability to perform highly accurate operations. According to Brown [Ref. 12:p. 151], the trackball is effective for fine cursor control tasks, such as target tracking.

Systems that require physical integrity, such as certain military systems, may also find the ability to mount the trackball in a keyboard or console to be an advantage or even a requirement, especially for mobile or combat systems. Still another advantage of the trackball is identified by Kalb [Ref. 9:p. 54], who claims that the trackball can be a good pointing device for the physically challenged who may not have the dexterity to operate other devices.

One disadvantage of the trackball is that it is harder to control than the mouse while performing essentially similar tasks. "The general design of most trackballs does not use the design of the hand efficiently." [Ref. 19:p. 217]

Other disadvantages are that trackballs tend to cost more than mice, and are generally less familiar to most users. For the generic input tasks discussed in Chapter I, the mouse has been found to be generally preferable to the trackball [Ref. 8:p. 108].

2. Best Uses for Trackball

Due to its stationary nature, a trackball is often preferred for use on systems with restricted desktop space and for systems that may be operated by a physically handicapped person. Because of their ability to provide fine cursor control, trackballs are commonly used on systems that require object or target tracking such as air radar tracking systems.

E. SUMMARY OF ALTERNATIVE INPUT TECHNOLOGIES

Each type of input device discussed here has unique advantages and disadvantages. Although selection of the proper input device can be crucial to system effectiveness, there is no recipe for selecting one of these devices in favor of another for a given system. Only specific system requirements such as information display, data entry requirements, physical size, and user capabilities ultimately can define the best input device for that system.

System developers can properly choose among input device alternatives by becoming familiar with the general limitations and capabilities of each. While each system will undoubtedly have unique requirements, knowledge of the availiable devices will provide for wiser and more informed decisions. Table 4 provides a summary of characteristics for touch screen, mouse, and trackball.

TABLE 4. SUMMARY OF TOUCH SCREEN, MOUSE, AND TRACKBALL CHARACTERISTICS. [Ref. 12:pp. 154, 155]

	Device Touch Screen	Mouse	Trackball
Uses	Select	Point, Select, Draw, Drag, Move cursor	Track, Select, Move cursor
Disadvantages	Accidental activation, Arm fatigue	Needs desk space, Has a trailing cord	Mouse faster for selecting text
Recommended For	Infrequent use, Coarse pointing	Highly interactive graphical interfaces	Precise pointing
Not Recommended For	Continuous use, Moderately precise pointing	Frequent mouse-to-keyboard changes	Frequent trackball-to-keyboard changes
Comments	Provide an arm rest	Mouse buttons add functional capability	Provide for left-handed users

III. SURVEY OF TOUCH SCREEN IOS USERS

A. GOAL OF THE SURVEY

The goal of this study is to provide NTSC with data that can be used to determine the best type of input device for specific IOS-related input tasks. As reported in Chapter II, information was collected from the literature on the various kinds of input devices and on proposed best uses for each. In addition, instructors and operators at the flight simulator sites listed in Chapter I were queried to determine their opinions concerning touch screen systems. These five simulators were selected because each incorporates a touch screen as part of the data entry and/or control systems.

A questionnaire was used to survey the instructors and operators. It consisted of 13 questions, including simple "yes/no" questions, rating scales, and open-ended questions. Background questions included the type of training system used by the respondent, the respondent's experience level with respect to that system, and the respondent's familiarity with various input devices. The remainder of the survey solicited opinions on various issues surrounding the employment of touch screen systems for data input for the respondents' specific systems.

B. QUESTIONNAIRE DEVELOPMENT

The questionnaire used in this study (Appendix A) was influenced by the U.S. Army's Questionnaire Construction Manual [Ref. 20:pp. 1-219]. Further, because there was no known study regarding the use of touch screens on military flight simulators, the questionnaire was designed to obtain a broad sweep of information. Therefore, the questionnaire solicicted descriptive information about the users as well as their opinions on the use of touch screen with their individual systems.

Topics covered by the questionnaire were defined based on issues identified through literature review, and the application of these issues to military flight simulators. The Questionnaire Construction Manual [Ref. 20] provided several possible formats for the questions. No single format was chosen, but rather several types were used, as appropriate for the variety of information solicited.

For questionnaires administered through the mail, a cover sheet was developed to explain the nature and purpose of the study. The first portion of the questionnaire solicited descriptive information about the participants. Recognizing that various touch screen implementations were being used throughout the Navy, Air Force, and Marine Corps, participants were asked to identify the simulator type they were familiar with.

The level of experience of the instructors and operators was requested in order to compare survey results with findings represented in the literature. The frequency with which the instructors and operators interact with their systems was determined next. This question listed four categories, ranging from "less than once per month" to "daily." Respondents were asked to circle the appropriate choice. This type of format was chosen for ease of analysis. The next three questions dealt with respondents' familiarity with mouse, trackball, and touch screen devices. Response options ranged from "none" to "very high."

The remaining portion of the questionnaire was aimed at collecting the opinions of the respondents about input tasks, effort required, and problems experienced, and about their feelings concerning use of a touch screen for their particular systems. Respondents were asked to indicate the percentage of time spent on each kind of input task, and whether a separate input task called "target building" should be added to the usual set of four input tasks (listed in Table 1, page 9). This question was included at the request of NTSC.

According to modern literature, highly accurate cursor positioning is a requirement that can be best achieved using the trackball or mouse. Therefore, survey participants were asked how important highly accurate target or cursor positioning is for their systems. Respondents were given a

list of five options to choose from, ranging from "undesirable" to "vital", with one option being "no opinion."

A simple "yes" or "no" response was used to determine whether parallax is a problem for the respondents' systems. An open-ended format was used to determine the number of minutes before arm fatigue is experienced by the respondents.

Instructors' and operators' overall opinions regarding the use of touch screens on their respective systems were obtained by having them select one statement (out of four) that best described their feelings. The first statement was designed to obtain data regarding the ability of other input devices to perform tasks that touch screens are now used for on these flight simulators. The second and third statements gave respondents the opportunity to indicate frustration stemming from common touch screen limitations. The fourth statement allowed respondents to indicate strong approval for touch screens as used by their particular systems.

The final question solicited respondents' opinions or comments on any topic related to the survey. An open-ended format was chosen to allow for maximum flexbility, and to permit respondents to elaborate on various answers in a single location on the questionnaire form.

C. QUESTIONNAIRE ADMINISTRATION

A total of 54 flight training system instructors and operators were surveyed. This is roughly half of all

possible Western United States flight simulator IOS users. The sample was considered to be representative of all instructors and operators of military systems of this type. The method of sampling used most closely resembles the stratified sampling model described by Denzin [Ref. 21:p. 73]. Using this model, each of the simulator sites surveyed represents a stratum.

Instructors are trained aviators, either active-duty or retired military. Operators are trained computer technicians who assist the instructors with system set-up, data input, and trouble-shooting. When a student's simulator session does not require the expertise of an instructor, operators can conduct entire training sessions without the presence of an instructor.

Of the 54 individuals surveyed, 34 were instructors and 20 were operators. All individuals surveyed were males. The average experience level on the system for which the individuals were being surveyed was 26 months, which is representative of most military flight simulator instructors and operators currently working with touch screen systems.

The questionnaires were administered personally at Luke Air Force Base and Lemoore Naval Air Station. The questionnaires for the simulator sites at Yuma and El Toro were administered by mail. A detailed cover sheet was provided with the mailed questionnaires, and supplemental assistance was given by telephone.

IV. DATA ANALYSIS AND RESULTS

A. DATA ANALYSIS

The responses to the IOS touch screen survey questionnaires were coded, compiled, and analyzed using the SPSSx statistical package on an IBM System 370 mainframe computer. The SPSSx Pearson Correlation function was used to compile responses into a matrix format and to obtain statistical correlation values among all responses. Descriptive statistics and cross tabulations were examined to determine trends in the data. Summary results are provided in Appendix B.

A practical approach was used for analysis, combining statistical correlations with apparent trends in the survey findings. This allowed for a wider analytical examination of the data as well as appropriate groupings of data. The primary method for comparing grouped responses was through cross tabulation.

B. SUMMARY PROFILE OF RESPONDENTS

1. Simulator Type

The frequency count and percentage of instructors and operators from each simulator site surveyed are listed in Table 5. The table indicates that there was balance

among the numbers of instructors, operators, and simulator types surveyed.

TABLE 5. PROPORTIONS OF PARTICIPANTS USING THE FIVE SIMULATOR TYPES.

Simulator Type	Instructors	Operators	Total Users	Percent
F-16C	7	3	10	18.52
F-15E	5	10	15	27.78
A-7E	5	3	8	14.81
AV-8B	5	4	9	16.67
F/A-18	12	0	12	22.22
Total	34	20	54	100.00

2. Level of Experience

The respondents' level of experience reflects the number of months that the individual has with simulators that use touch screen technology for data input. The average experience level was found to be 26 months, as shown in Table 6.

TABLE 6. RESPONDENTS' LEVELS OF EXPERIENCE

Simulator Type	Respondents' Average Experience Level, Months
F-16C	38.3
F-15E	18.1
A-7E	21.0
AV-8B	34.6
F/A-18	23.0
All instructors	26.0
All operators	26.3
Total	26.1

3. System Interaction

Most respondents (83%) interact with their systems daily. In fact, all of the respondents interact with their systems at least monthly. Table 7 illustrates how often the respondents interact with their touch screen systems.

TABLE 7. AMOUNT OF INTERACTION WITH TOUCH SCREEN SYSTEMS

Response	Response Frequency	Percent of Total
Less than once per month	0	0.0
At least once per month	5	9.3
At least once per week	4	7.4
Daily	45	83.3
Total	54	100.0

4. Familiarity With Input Devices

Several questions dealt with the respondents' familiarity with mouse, trackball, and touch screen. Most participants have some degree of familiarity with all three devices, although most have a higher degree of familiarity with touch screens.

Tables 8, 9, and 10 list the findings for mouse, trackball, and touch screen familiarity. Touch screens are by far the most familiar input device, with 80% of the respondents listing their familiarity as high or very high. The mouse and trackball were both found to be less familiar than touch screen to the respondents.

Mouse familiarity was listed as high or very high 35% of the time, while trackball familiarity was listed as high or very high 30% of the time. More than half of the respondents listed mouse and trackball familiarity as low or medium (54% and 52% respectively), while 20% listed touch screen familiarity as either low or medium.

TABLE 8. MOUSE FAMILIARITY

Familiarity	Response Frequency	Percent
None	6	11.1
Low	20	37.0
Medium	9	16.7
High	12	22.2
Very high	7	13.0
Total	54	100.0

TABLE 9. TRACKBALL FAMILIARITY

Familiarity	Response Frequency	Percent
None	10	18.5
Low	13	24.1
Medium	15	27.8
High	10	18.5
Very high	6	11.1
Total	54	100.0

TABLE 10. TOUCH SCREEN FAMILIARITY

Familiarity	Response Frequency	Percent
None	0	0.0
Low	3	5.6
Medium	8	14.8
High	23	42.6
Very high	20	37.0
Total	54	100.0

C. SUMMARY OPINIONS ON THE USE OF TOUCH SCREEN

1. Types of Tasks Being Performed

Question 7 asked respondents to approximate the amount of their overall input effort that is expended performing various touch screen tasks. The question made use of the four generic input tasks set forth by Foley [Ref. 5] in Chapter I and one additional area to provide for miscellaneous responses, called "other". Ratings on a 20 point scale from 0% to 100% were used to represent the percentage of the overall input effort expended performing each task. Figures 9 through 13 provide histograms from the SPSSx output illustrating the response frequencies for percentages of time spent on positioning, selection, text entry, path, and "other" tasks.

```
NUMBER OF
RESPONSES      VALUE    ONE SYMBOL EQUALS APPROXIMATELY    .60 OCCURRENCES

      26         .00   *******************************************
      14       20.00   ***********************
       3       40.00   *****
       3       60.00   *****
       1       80.00   **
       1      100.00   **
                       I.........I.........I.........I.........I.........I
                       0         6        12        18        24        30
                                  "POSITIONING" INPUT TASKS

Valid cases       48      Missing cases      6
```

Figure 9. Percentage of Touch Screen Input Time Spent on Positioning Tasks.

A total of 83% of the respondents claimed that positioning tasks account for 20% or less of their touch screen input. More than half of these respondents (54%) claimed that they do not use touch screen for positioning at all. The remaining 17% reported that they use their touch screen for positioning more than 20% of the time.

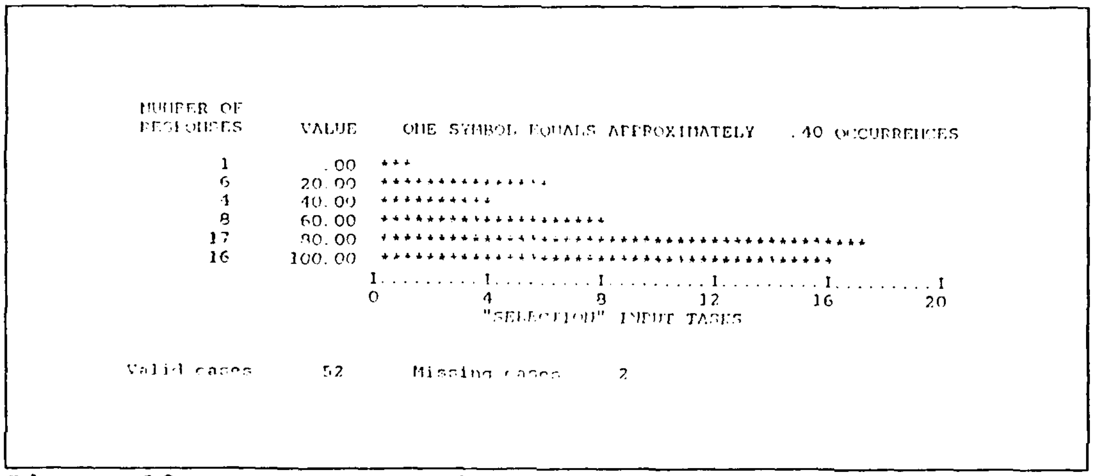

Figure 10. Percentage of Touch Screen Input Time Spent on Selection Tasks.

Selection tasks account for most of the touch screen input effort expended by instructors and operators. A total of 79% of the respondents reported that selection tasks account for 60% or more of their overall input effort. Of those, 63% said that selection accounts for 80% or more of the input tasks performed.

```
NUMBER OF
RESPONSES      VALUE     ONE SYMBOL EQUALS APPROXIMATELY     .80 OCCURRENCES

      39         .00   ************************************************
       6       20.00   ********
       1       40.00   *
       1       60.00   *
       1       80.00   *
       1      100.00   *
                       I.........I.........I.........I.........I.........I
                       0         8        16        24        32        40
                                "TEXT ENTRY" INPUT TASKS

Valid cases      49      Missing cases      5
```

Figure 11. Percentage of Touch Screen Input Time Spent on Text Entry Tasks.

Nearly 80% of the respondents claimed that they do not use a touch screen for text, path, or other tasks. Ratings of 0% were given for text entry tasks by 79% of the respondents, for path tasks by 88% of the respondents, and for "other" by 82% of the respondents.

```
NUMBER OF
RESPONSES      VALUE     ONE SYMBOL EQUALS APPROXIMATELY     .80 OCCURRENCES

      38         .00   ***********************************************
       2       20.00   ***
       2       40.00   ***
       0       60.00
       0       80.00
       1      100.00   *
                       I.........I.........I.........I.........I.........I
                       0         8        16        24        32        40
                                "PATH" INPUT TASKS

Valid cases      43      Missing cases     11
```

Figure 12. Percentage of Touch Screen Input Time Spent on Path Tasks.

```
NUMBER OF   PERCENT
RESPONSES   RATING   ONE SYMBOL EQUALS APPROXIMATELY   .40 OCCURRENCES

    18         .00  *********************************************
     1       20.00  ***
     2       40.00  *****
     0       60.00
     0       80.00
     1      100.00  ***
                    I.........I.........I.........I.........I.........I
                    0         4         8        12        16        20
                              "OTHER" INPUT TASKS

Valid cases      22      Missing cases    32
```

Figure 13. Percentage of Touch Screen Input Time Spent on "Other" Tasks.

A cross tabulation relating simulator type to the amount of positioning and selection being performed reveals that 83.4% of the respondents use a touch screen for positioning tasks 20% of the time or less. Conversely, 78.9% use touch screen for selection tasks 60% of the time or more. Average percentages of time spent in these two tasks, as a function of simulator type, are given in Table 11.

TABLE 11. AVERAGE PERCENT OF TIME SPENT IN POSITIONING AND SELECTION TASKS, BY SIMULATOR TYPE.

Simulator Type	Percent of Time	
	Positioning Tasks	Selection Tasks
F-16C	36	64
F-15E	0	80
A-7E	8	85
AV-8B	10	73
F/A-18	14	45

2. Target Building

Question 8 asked for the instructors' and operators' opinions regarding whether a task called "target building" should be added to the list of kinds of tasks performed. NTSC desires information on the establishment of target building as a unique input task, to be considered separately during system development. Table 12 lists the responses to this question. However, these responses are not applicable to this study and will not be discussed further.

TABLE 12. RESPONDENTS' OPINIONS ABOUT ESTABLISHMENT OF A SEPARATE INPUT TASK CATEGORY CALLED "TARGET BUILDING"

Opinion	Response Frequency	Percent
Yes	14	28.0
No	16	32.0
No opinion	20	40.0
Total	50	100.0

3. Amount of Accuracy Required

Table 13 provides a summary of the respondents' opinions regarding the need for highly accurate target or cursor positioning for their respective systems. Most respondents (47%) said that highly accurate target or cursor positioning is unnecessary for operating their simulators. The next largest group reported that this type of accuracy is

important (25%), followed by those claiming that this type of accuracy is vital for system operation (16%).

TABLE 13. RESPONDENTS' ASSESSMENT OF THE NEED FOR HIGHLY ACCURATE CURSOR POSTIONING.

Response	Response Frequency	Percent
Undesirable	1	2.0
Unnecessary	24	47.0
Important	13	25.5
Vital	8	15.7
No opinion	5	9.8
Group	51	100.0

4. Parallax

Overall, roughly two-thirds (69%) of the respondents do not find parallax to be a problem with their systems. However, responses were strongly influenced by the type of touch screen technology used for the various systems.

The A-7E and F/A-18 both use capacitance sensing touch screens; 10 out of 19 respondents (53%) report that parallax is a problem. The F-16C and the AV-8B both use optical touch screens; 6 out of 19 surveyed (32%) believe parallax is a problem with their system. The F-15E, which uses resistive membrane screens, gave totally different results. None of the 13 respondents reported that parallax is a problem with their system. Table 14 provides a breakdown of the responses to this question.

TABLE 14. IS PARALLAX A PROBLEM ?

Simulator Type	"Yes"	"No"	Total Responses
F-16C (optical)	5	5	10
F-15E (resistive)	0	13	13
A-7E (capacitive)	5	3	8
AV-8B (optical)	1	8	9
F/A-18 (capacitive)	5	6	11
Total (percent)	16 (31)	35 (69)	51 (100)

5. Arm Fatigue

Another area explored by the questionnaire is arm fatigue. A total of 88% of the respondents reported they do not experience arm fatigue at all while using their respective touch screens. Relatively few respondents (6 out of 52) indicated that arm fatigue was ever experienced. Table 15 lists the breakdown of answers to this question, including the types of simulators used by those who experience arm fatigue.

TABLE 15. TIME BEFORE ARM FATIGUE IS EXPERIENCED

Minutes Before Arm Fatigue Is Experienced	Response Frequency	Percent	Simulator Type
10	2	3.9	AV-8B, F/A-18
20	1	1.9	AV-8B
35	1	1.9	F-16C
40	1	1.9	F-15E
120	1	1.9	F-15E
Never	46	88.5	All
Total	52	100.0	

6. Respondents' Feelings Regarding Touch Screen

Nearly one-half (47%) of the respondents indicated that they feel a touch screen is the ideal input device, as employed by their respective systems. One-third (33%) feel that other devices could perform better than or equally as well as touch screen on their respective systems. The general feelings of the instructors and operators surveyed are highlighted in Table 16.

TABLE 16. OVERALL FEELINGS REGARDING USE OF TOUCH SCREEN

OPTIONS TO CHOOSE FROM	FREQUENCY	PERCENT
Other input devices could perform better than or equally as well as touch screen on a system like this.	17	33.3
Touch screen would be better suited for a system that requires little or no operator expertise.	5	9.8
Touch screen is cumbersome due to dirty screens, parallax, and inaccuracy.	5	9.8
Touch screen is the ideal input device for a system of this type.	24	47.1
Total	51	100.0

A comparison between the respondents' simulator type and their overall feelings toward touch screens showed no discernible preference for a particular type of touch screen technology. The majority of AV-8B and F-15E instructors and operators (7 out of 8, and 12 out of 14, respectively) feel that a touch screen is the ideal input device. The AV-8B uses an IR touch screen while the F-15E uses resistive membrane.

The majority of F-16C respondents (7 out of 10) feel that other devices could perform better than or equally as well as a touch screen on their system. The F-16C touch screen is an IR type. Instructors and operators for the A-7E and F/A-18 showed no majority of opinion regarding their

feelings toward the use of touch screen on their systems. Both of these simulators use capacitive-type touch screens. Table 17 shows the sub-totals, according to simulator type, of responses to this question.

TABLE 17. FEELINGS REGARDING USE OF TOUCH SCREEN, AS A FUNCTION OF SIMULATOR TYPE.

Sim. Type	Other Devices Better or Equal	Requires Little Expertise	Touch Screen Cumbersome	Touch Screen Ideal	Total Responses
F-16C	7	1	1	1	10
F-15E	1	1	0	12	14
A-7E	4	2	0	2	8
AV-8B	1	0	0	7	8
F/A-18	4	1	4	2	11
TOTAL	17	5	5	24	51

D. RESPONDENTS' COMMENTS

The last survey question gave respondents the opportunity to comment on the systems or to discuss other issues pertaining to the IOS. One-half of the 54 indivduals surveyed provided comments. These comments are summarized and discussed below.

1. Comments Favorable to Use of a Touch Screen

Favorable touch screen comments center around ease of use and training, efficiency stemming from the ability to centralize data presentation, and convenience. One respondent writes, "I can't think of a better way to present multi-menu displays as efficiently as touch screens." Another writes

that inexperienced operators are able to use the system easily and that "input can be structured to make it straightforward."

2. Comments Unfavorable to Touch Screen Use

Unfavorable attitudes concerning touch screen center around technical aspects such as slowness, parallax, and overly complex interface designs. For example, IR touch screens require that the light beam is broken directly over the object to be selected. If the instructor or operator breaks the beam by touching the screen at an angle, there is a good chance of selecting the wrong object. The system interprets the point of location to be different than what is desired or an additional, unwanted selection is made.

Slow response time is also attributed to certain touch screen implementations. One respondent writes that "delays of several seconds can be significant during certain tactical and time-critical scenarios." Parallax is seen as causing the need for multiple attempts before the correct selection "takes." Menu design complexity is another area resulting in cumbersome operations for these touch screen users.

Given the overall design complexity of today's military flight simulators, instructors and operators must interface with massive amounts of information. When a touch screen is used for data entry, this often requires a large hierarchy of menu layers. "It is very easy to get lost in

menus that are nested 5 and 6 levels deep," writes one respondent.

3. Other Comments

A neutral attitude exists among the respondents regarding the employment of touch screens on flight simulators today. This attitude is basically a compromise position which recognizes the strengths and weaknesses of touch screens as well as other devices, and recommends a combination of devices. For example, one instructor claims that "touch screen is good for certain tasks but data entry for motion paths and target specifics require other modality." Another writes, "A combination of touch screen, joystick, and keyboard would work much better than any single system. Quit trying to pidgeon-hole entry devices!"

E. PERSONAL OBSERVATIONS

Observations made while performing this study provide additional insight to the data obtained from the survey and the literature review. The simulator sites that were visited personally provide the majority of these observations. However, casual conversations and supplemental information gathered in the process of conducting the study also provide input to these observations. Since the designs of the various IOS systems differ widely, each will be discussed separately.

1. F-16C Simulator IOS

The F-16C simulator IOS is designed for all of the input and most of the monitoring to be done through a single monitor, using a highly graphical interface. System interaction is centralized in that the training scenario revolves around this one monitor. Many "pages" of menus are needed due to the centralized display of information.

Most of the F-16C instructors use locally devised styli when performing data entry. These styli are similar to a pencil without the lead and facilitate selection accuracy by making it easier to make perpendicular contact with the optical screen, as is necessray to avoid mis-selection.

Simplicity of operation apparently was the overall goal for the design of this IOS, relative to others observed. However, the implementation actually resulted in increased complexity. For example, numeric calculations are performed by touching a menu item which brings up a new page with an image of a calculator on the infrared screen. The various "buttons" pictured on the calculator are programmed as menu items that are to be touched, like any other menu item. Moreover, the areas programmed to sense a menu selection vary. Some touch areas are rather small. If a mistake is made, the instructor may need to access several pages to correct it. The instructors and operators of this system appeared to experience a higher degree of dissatisfaction and frustration than those with differently designed IOSs.

2. F-15E Simulator IOS

The F-15E IOS implementation differs from the F-16C IOS in that touch screen input is limited to broad menu selections from monitors dedicated solely to this function. Additionally, the IOS is much more complex to look at because of its numerous monitors and panels (see Figure 1), but the input process is relatively simple. The touch screen may be used to select a general condition, for example, navigation training. Specific data, such as airspeed, are entered using a dedicated keypad. Numerous display monitors are used to enable the instructor to view the situation without much need for changing what is being displayed on the screens.

3. A-7E Simulator IOS

The A-7E simulator added a panel of three capacitance-sensing touch screen monitors to previous versions of its IOS several years ago. These touch screens are used only for simulated weapons loads. The instructors and operators perform input through a menu-driven interface. Informal conversation indicated that the touch screens on this system are unreliable, but hat the effect of this unreliability is minimal due to the ability to use a keyboard when the touch screen is down.

4. AV-8B and F/A-18 Simulator IOSs

The AV-8B (Figure 2) and F/A-18 IOSs make use of a design methodology similar to that of the F-15E IOS. These

IOSs appear to be sophisticated, as does the training being conducted with them. However, the overall result of dividing the various input functions among several devices is greater simplicity.

5. Overall Implications of IOS Designs

In general, the above observations concerning the various IOS systems imply that those systems designed to make prudent use of touch screens are enjoying a higher degree of satisfaction by the users. Conversely, the use of touch screens for all kinds of data entry tasks appears to increase the users' frustration by asking too much from the device.

Choice of an alternative input device must be done with full awareness of the overall flight simulator IOS design strategy. The device chosen and the strategy for IOS design can result either in satisfaction or frustration for its users.

V. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

1. Experience Level

The experience level of the IOS users surveyed is higher than what is recommended in the literature for IOS users. As is noted in Chapter II, researchers suggest that inexperienced users benefit most from touch screen input methods. The average experience level of the indivduals surveyed is nearly 4 years (Table 6).

2. Frequency of Interaction

The frequency with which the IOS users surveyed interact with their systems is higher than what is recommended by literature. Touch screens are recommended for applications requiring infrequent interaction with the system (Table 4). The vast majority (83%) of IOS users surveyed interact with their systems on a daily basis (Table 7).

3. Familiarity With Other Devices

Tables 8 and 9 indicate that the IOS users surveyed are already familiar with the mouse and the trackball. Thus, incorporation of such input devices into IOS systems should require little additional training and minimal problems.

4. Tasks Being Performed With Touch Screen

The simulators studied use touch screens primarily for selection tasks. However, survey results indicate that instructors and operators who must carry out numerous positioning tasks feel that other devices could perform better than or equally as well as touch screens (Tables 11 and 17).

This is exemplified by the F-16C simulator IOS, which is used for positioning tasks more than twice as much as any of the other simulators surveyed (Table 11). The F-16C simulator makes use of a highly graphical interface for all input tasks, which may make the situation worse. As shown in Table 4, researchers recommend the mouse for highly graphical interfaces. Table 17 suppports this recommendation by indicating that the F-16C IOS users feel that other input devices could perform better than or equally as well as touch screen on their system.

Survey results also show that the Navy, Air Force, and Marine Corps are using touch screens to perform tasks that are not well suited for that type of input device, yet with apparent success. Table 1 indicates that, according to recent literature, the mouse or trackball are the preferred input devices for positioning tasks. Table 11 indicates that several of the Navy, Air Force, and Marine Corps flight simulators require users to perform certain postioning tasks using touch screens. However, these results do not say that other devices might not actually be preferred over touch

screens for positioning, only that touch screens are being used with relatively satisfactory outcomes.

5. Degree of Accuracy Required

The amount of accuracy needed for target or cursor positioning on these systems does not seem to affect the users' responses to other issues. Table 13 indicates that most respondents feel that such cursor or target positioning is unnecessary on their system.

6. Parallax

Parallax is a problem on the systems surveyed in this study, based on the opinions of 31% of the respondents (Table 14). However, this problem exists primarily with capacitive and optical touch screen devices, not with resistive membrane systems.

7. Arm Fatigue

Arm fatigue is not a problem that can be associated with the simulators surveyed in this study (Table 15).

8. Feelings Toward Touch Screen

The majority opinion of the IOS users surveyed is that a touch screen is the ideal input device as used on their systems (Table 16). These feelings appear to be implementation-dependent. Table 17 indicates that the F-15E and the AV-8B IOS users represent the majority of those who feel that the touch screen is the ideal input device, as implemented on their systems.

Through observation, it was noticed that these systems incorporate similar IOS design strategies. Both simulators limit the use of the touch screen primarily to menu selection (Table 11). Further, these simulators use touch screens in an integrated fashion. That is, other devices are used in concert with touch screens to effect system input. The implementation of touch screens on these systems adheres closely to what the literature suggests as best uses for touch screens, as reported in Chapter II.

9. Addition of Mouse or Trackball to the IOS

Throughout this study, the ability of mouse or trackball to perform the tasks being performed via touch screen was considered. It does not appear that those systems that use touch screens in a limited sense (for example, menu selection) would benefit from the addition of a mouse or trackball.

However, a mouse could be used to perform some of the tasks currently carried out via the touch screen on the F-16C simulator. There are two reasons for this assessment. First, modern literature suggests that highly graphical interfaces, like that employed by this simulator, are best suited for control via a mouse. Second, the F-16C simulator already has an optical mouse that can be used satisfactorily with the system. The mouse is currently used occasionally by maintenance operators, but is not used for training sessions.

The F-16C IOS mouse is capable of performing all functions that the optical touch screen performs.

The effectiveness of the IOS mouse was observed to be equal to that of the touch screen, based on a short demonstration which did not include any positioning tasks. If positioning tasks also are considered, use of a mouse is expected to result in better performance than use of a touch screen.

B. RECOMMENDATIONS

1. Consider Alternatives and IOS Design

The results of this study suggest that, along with a touch screen, the mouse and trackball should be considered as alternative input devices for flight simulator IOS systems, as these systems are developed and improved. Which device is actually selected must depend on the overall system design and layout, and on the kinds of input tasks required of the instructor and operator. Data provided in Tables 1, 3, and 4, and throughout Chapter IV can be used in determining the best general type of input device and the best implementation technology for a given system and its required tasks.

The findings of this study do not invalidate the findings of other studies. Rather, results reported here can be used to supplement previous research findings. The successful IOS designs noted in the study and the opinions of the instructors and operators of these simulators strongly

indicate that matching input tasks with appropriate input devices is critical for optimum design of flight simulator IOS systems.

2. Further Study

Further study related to alternative input device selection for automated military training systems is recommended. The study reported here focused on flight simulator IOS systems, yet was necessarily broad in its coverage due to the lack of existing data in the field. Therefore, benefit can be gained from focusing on a particular aspect of the data gathered in this study.

For example, the F-15E and AV-8B instructors and operators appear to be more satisfied with touch screens than other instructors and operators. This seems to be due to the manner in which these systems integrate the touch screens into their overall IOS design. Further study is needed to determine precisely what aspects of integrated IOS design have resulted in higher user satisfaction for these systems.

APPENDIX A

INPUT TASKS AND DEVICES QUESTIONNAIRE

This questionnaire is designed to provide the Naval Training Systems Command (NTSC) in Orlando, Florida, with vital information regarding the design of the Instructor/Operator Station (IOS) in modern automated training systems. In particular, this questionnaire focuses on the area of alternative input devices. The results will be used to provide guidelines for selecting among these various alternatives.

The questionnaire has been designed by LT Alan Vazquez, USN, as part of a Master's thesis. Respondents of this questionnaire will be providing valuable military-specific feedback which will lead to improved selection guidelines for the military.

Thank you for your valuable time and knowledge. Questionnaire results and a copy of this thesis will be on file at the Naval Postgraduate School, Monterey, CA.

LT Alan A. Vazquez
Computer Systems Management
Naval Postgraduate School

Form No.____

INPUT TASKS AND DEVICES QUESTIONNAIRE

PURPOSE: Information from this questionnaire will be used to determine the general types of input tasks being performed and the input devices that should be used for automated training systems today.

Instructions: Please indicate the BEST response to each question. Answers should be based on the training system you are CURRENTLY working with.

1. Training device name or designation: ____________________
   (ex. F-16A/C, AV-8B, A-7E, etc.)

2. Indicate your approximate level of experience on this system in years and/or months: (ex. 1 year 10 months, etc.)

   ____

3. Indicate your frequency of interaction with the system: (circle one)

   less than once per month   at least once per month

   at least once per week   daily

4. Your familiarity with a "mouse" is (circle one)

   none   low   medium   high   very high

5. Your familiarity with a trackball is (circle one)

   none   low   medium   high   very high

6. Your familiarity with touch screens is (circle one)

   none   low   medium   high   very high

7. Several categories of input tasks are listed below. In the matrix below, indicate the relative proportion of time you spend using the touch screen to perform these tasks by placing an X in the appropriate column. If you do not use the touch screen for a task mark the "0%" column. If you spend ALL your time using touch screen for a particular task mark the "100%" column, etc. Treat each category separately (do not worry about choices adding to equal 100.)

Sample tasks:

positioning - placement of the target or cursor at a specific point on the screen.

selection - choosing an item from a set of alternatives (ex. menu selection)

text entry - specifying a sequence of symbols, such as composing a filename.

path - similar to positioning except a straight or curved direction results from several points.

other - a task that you feel does not belong to any categories listed above.

		Percentage of Input Time Spent					
		(none) 0%	20	40	60	80	100% (all)
Type of Task	positioning	___	___	___	___	___	___
	selection	___	___	___	___	___	___
	text entry	___	___	___	___	___	___
	path	___	___	___	___	___	___
	other	___	___	___	___	___	___

If other, please describe :______________________________________
____

8. In your opinion, should an additional input task category called "target building" be added to the list in Number 7 above ? (circle one)

Yes No No Opinion

If yes, briefly describe what this task might consist of ______________
____
____
____

9. For this system, highly accurate target or cursor positioning is (circle one)

undesirable unnecessary important vital no opinion

10. Is parallax a problem with this touch screen system ? (circle one)

Yes No

11. How long (in minutes) is it before arm fatigue sets in when using a touch screen ? (ex. 10 mins., 120mins., etc.) If fatigue is never experienced, write N/A.

____

12. Select the option that BEST describes your feelings regarding use of a touch screen for your system: (check one)

___ Other input devices could perform better than or equally as well as touch screen on a system like this.

___ Touch screen would be better suited for a system that requires little or no operator expertise.

___ Touch screen is cumbersome due to dirty screens, parallax, and inaccuracy.

___ Touch screen is the ideal input device for a system of this type.

13. Use the space below to explain your answer(s) or discuss other issues and/or opinions as required: ______________________________

THANK YOU FOR YOUR ASSISTANCE !

APPENDIX B

RESULTS OF SURVEY

The results of the Input Tasks and Devices Survey are given in the following appendix. Answers to each question on the survey are given for individual respondents, allowing for further analysis. Each respondent's answers correspond to each of the 54 "cases" listed in the left column of each page. All other columns represent survey questions.

The column titled "Type of Simulator" lists the type of simulator the respondent is associated with, as well as his status as either an instructor or operator. The number indicates the simulator type. An "M" (maintenance) indicates that the respondent is an operator of that system. An "I" (instructor) indicates that the respondent is an active-duty instructor, which was not handled separately from contract instructor in this study. The absence of a letter indicates that the respondent is a contract instructor for that system.

The column titled "Frequency of Interaction" uses the symbol ">=" to represent "greater than or equal to." A "." or "-1" indicates that no response was given for that question. These were dealt with as "missing values" by SPSSx. All other responses are self-explanatory.

CASE	TYPE OF SIMULATOR	MONTHS OF EXPERIENCE	FREQUENCY OF INTERACTION
1	16	22	DAILY
2	16M	96	DAILY
3	16M	24	DAILY
4	16	24	DAILY
5	16	25	DAILY
6	16	24	>= ONCE PER WEEK
7	16	72	DAILY
8	16	24	DAILY
9	16	24	DAILY
10	16M	48	DAILY
11	15	12	DAILY
12	15	18	DAILY
13	15	12	DAILY
14	15	12	>= ONCE PER WEEK
15	15	24	DAILY
16	15M	21	DAILY
17	15M	7	DAILY
18	15M	11	DAILY
19	15M	12	DAILY
20	15M	8	DAILY
21	15M	18	DAILY
22	15M	21	DAILY
23	15M	60	DAILY
24	15M	22	DAILY
25	15M	13	DAILY
26	7I	36	>= ONCE PER MONTH
27	7I	24	>= ONCE PER MONTH
28	7M	42	DAILY
29	7I	6	>= ONCE PER MONTH
30	7I	6	>= ONCE PER WEEK
31	7I	24	>= ONCE PER MONTH
32	7M	8	DAILY
33	7M	22	DAILY
34	8	72	DAILY
35	8	24	DAILY
36	8	56	DAILY
37	8I	6	>= ONCE PER MONTH
38	8M	12	DAILY
39	8M	14	DAILY
40	8M	31	DAILY
41	8M	36	DAILY
42	8	60	>= ONCE PER WEEK
43	18	18	DAILY
44	18	14	DAILY
45	18	48	DAILY
46	18	18	DAILY
47	18	12	DAILY
48	18	3	DAILY
49	18	54	DAILY
50	18	16	DAILY
51	18	3	DAILY
52	18	14	DAILY
53	18	58	DAILY
54	18	18	DAILY

CASE	MOUSE FAMILIARITY	TRACKBALL FAMILIARITY	TOUCH SCREEN FAMILIARITY
1	NONE	NONE	VERY HIGH
2	HIGH	MEDIUM	HIGH
3	VERY HIGH	HIGH	VERY HIGH
4	VERY HIGH	MEDIUM	VERY HIGH
5	HIGH	MEDIUM	VERY HIGH
6	VERY HIGH	VERY HIGH	VERY HIGH
7	LOW	LOW	HIGH
8	LOW	LOW	VERY HIGH
9	MEDIUM	MEDIUM	VERY HIGH
10	LOW	NONE	VERY HIGH
11	MEDIUM	MEDIUM	HIGH
12	HIGH	HIGH	HIGH
13	HIGH	HIGH	HIGH
14	NONE	LOW	HIGH
15	MEDIUM	MEDIUM	HIGH
16	LOW	LOW	HIGH
17	LOW	LOW	HIGH
18	LOW	VERY HIGH	VERY HIGH
19	LOW	LOW	HIGH
20	LOW	MEDIUM	HIGH
21	LOW	NONE	HIGH
22	HIGH	LOW	VERY HIGH
23	MEDIUM	NONE	HIGH
24	VERY HIGH	MEDIUM	VERY HIGH
25	HIGH	NONE	VERY HIGH
26	LOW	LOW	MEDIUM
27	MEDIUM	MEDIUM	HIGH
28	VERY HIGH	VERY HIGH	VERY HIGH
29	LOW	LOW	MEDIUM
30	MEDIUM	LOW	MEDIUM
31	NONE	NONE	MEDIUM
32	NONE	NONE	HIGH
33	LOW	NONE	VERY HIGH
34	LOW	LOW	VERY HIGH
35	LOW	NONE	VERY HIGH
36	HIGH	MEDIUM	VERY HIGH
37	LOW	LOW	HIGH
38	HIGH	HIGH	HIGH
39	LOW	HIGH	VERY HIGH
40	LOW	NONE	VERY HIGH
41	VERY HIGH	MEDIUM	VERY HIGH
42	MEDIUM	MEDIUM	HIGH
43	MEDIUM	VERY HIGH	MEDIUM
44	MEDIUM	HIGH	HIGH
45	NONE	HIGH	HIGH
46	LOW	LOW	MEDIUM
47	LOW	MEDIUM	LOW
48	HIGH	HIGH	HIGH
49	HIGH	VERY HIGH	MEDIUM
50	HIGH	HIGH	MEDIUM
51	HIGH	MEDIUM	LOW
52	NONE	MEDIUM	LOW
53	VERY HIGH	VERY HIGH	HIGH
54	LOW	HIGH	HIGH

CASE	PER CENT POSITIONING	PER CENT SELECTION	PER CENT TEXT	PER CENT PATH	PER CENT OTHER
1	80	20	0	0	.
2	40	60	20	.	.
3	20	80	20	0	0
4	20	80	0	0	.
5	20	80	0	0	0
6	20	.	80	.	20
7	.	80	20	.	.
8	60	100	0	0	.
9	40	60	0	0	0
10	20	80	.	.	.
11	0	100	0	0	.
12	0	100	0	0	.
13	0	100	0	0	.
14	0	100	0	0	0
15	.	100	.	.	.
16	0	100	0	0	0
17	0	100	0	0	0
18	0	100	0	0	0
19	0	80	0	0	.
20	.	80	0	.	.
21	0	0	0	0	0
22	0	40	0	0	.
23	0	40	0	0	.
24	0	80	0	.	.
25	.	80	.	.	.
26	20	80	0	0	.
27	20	60	0	0	0
28	0	100	0	0	0
29	0	60	20	40	.
30	0	100	0	0	0
31	0	100	0	0	0
32	0	100	0	0	0
33	20	80	20	20	.
34	20	100	20	20	.
35	20	80	0	0	.
36	0	60	0	0	40
37	20	100	100	.	100
38	0	60	0	0	.
39	0	80	0	0	.
40	100	100	0	100	.
41	20	20	0	0	40
42	0	60	40	0	.
43	0	20	0	0	0
44	60	80	0	0	.
45	60	40	0	0	.
46	.	.	.	.	.
47	.	20	.	.	.
48	0	20	0	0	0
49	0	40	0	0	.
50	40	80	60	40	.
51	20	20	0	0	0
52	0	60	0	0	0
53	0	80	0	0	0
54	20	80	0	0	.

CASE	TARGET BUILDING	IMPORTANCE OF ACCURACY	IS PARALLAX A PROBLEM?
1	NO	IMPORTANT	YES
2	NO	IMPORTANT	NO
3	NO	UNNECESSARY	NO
4	NO	IMPORTANT	YES
5	NO	IMPORTANT	NO
6	NO	IMPORTANT	NO
7	YES	.	NO
8	YES	UNNECESSARY	YES
9	NO	UNNECESSARY	YES
10	YES	UNNECESSARY	YES
11	YES	UNNECESSARY	NO
12	YES	UNNECESSARY	NO
13	YES	UNNECESSARY	NO
14	YES	UNNECESSARY	NO
15	YES	UNNECESSARY	NO
16	YES	UNNECESSARY	NO
17	NO	UNNECESSARY	NO
18	NO	UNNECESSARY	NO
19	NO	UNNECESSARY	NO
20	NO	UNNECESSARY	NO
21	YES	UNNECESSARY	NO
22	YES	IMPORTANT	NO
23	.	.	.
24	NO	UNNECESSARY	NO
25	.	VITAL	.
26	NO OPINION	IMPORTANT	YES
27	NO OPINION	UNDESIRABLE	YES
28	NO OPINION	UNNECESSARY	NO
29	NO OPINION	UNNECESSARY	NO
30	NO OPINION	UNNECESSARY	YES
31	NO OPINION	UNNECESSARY	YES
32	NO OPINION	UNNECESSARY	NO
33	NO OPINION	UNNECESSARY	YES
34	NO OPINION	VITAL	NO
35	NO OPINION	UNNECESSARY	NO
36	YES	IMPORTANT	YES
37	NO OPINION	IMPORTANT	NO
38	NO OPINION	IMPORTANT	NO
39	NO	IMPORTANT	NO
40	NO OPINION	VITAL	NO
41	NO OPINION	NO OPINION	NO
42	NO	IMPORTANT	NO
43	.	VITAL	NO
44	YES	UNNECESSARY	NO
45	YES	VITAL	NO
46	.	.	.
47	NO OPINION	NO OPINION	YES
48	NO OPINION	VITAL	NO
49	NO OPINION	VITAL	YES
50	NO	VITAL	YES
51	NO OPINION	NO OPINION	YES
52	NO OPINION	NO OPINION	NO
53	NO OPINION	NO OPINION	NO
54	NO	IMPORTANT	YES

CASE	MINUTES BEFORE ARM FATIGUE	OVERALL FEELINGS
1	35	CUMBERSOME
2	.	OTHERS = OR BETTER
3	.	NO EXPERTISE REQ
4	.	OTHERS = OR BETTER
5	.	OTHERS = OR BETTER
6	.	OTHERS = OR BETTER
7	-1	OTHERS = OR BETTER
8	.	OTHERS = OR BETTER
9	.	OTHERS = OR BETTER
10	.	TOUCH SCREEN IDEAL
11	.	TOUCH SCREEN IDEAL
12	.	OTHERS = OR BETTER
13	.	TOUCH SCREEN IDEAL
14	.	.
15	40	TOUCH SCREEN IDEAL
16	.	TOUCH SCREEN IDEAL
17	.	TOUCH SCREEN IDEAL
18	.	TOUCH SCREEN IDEAL
19	.	TOUCH SCREEN IDEAL
20	120	TOUCH SCREEN IDEAL
21	.	TOUCH SCREEN IDEAL
22	.	TOUCH SCREEN IDEAL
23	.	NO EXPERTISE REQ
24	.	TOUCH SCREEN IDEAL
25	.	TOUCH SCREEN IDEAL
26	.	OTHERS = OR BETTER
27	.	OTHERS = OR BETTER
28	.	TOUCH SCREEN IDEAL
29	.	NO EXPERTISE REQ
30	.	OTHERS = OR BETTER
31	.	OTHERS = OR BETTER
32	.	TOUCH SCREEN IDEAL
33	.	NO EXPERTISE REQ
34	20	TOUCH SCREEN IDEAL
35	.	TOUCH SCREEN IDEAL
36	10	.
37	.	TOUCH SCREEN IDEAL
38	.	TOUCH SCREEN IDEAL
39	.	TOUCH SCREEN IDEAL
40	.	OTHERS = OR BETTER
41	.	TOUCH SCREEN IDEAL
42	.	TOUCH SCREEN IDEAL
43	.	OTHERS = OR BETTER
44	.	TOUCH SCREEN IDEAL
45	.	TOUCH SCREEN IDEAL
46	-1	.
47	.	CUMBERSOME
48	.	OTHERS = OR BETTER
49	.	CUMBERSOME
50	.	CUMBERSOME
51	10	CUMBERSOME
52	.	NO EXPERTISE REQ
53	.	OTHERS = OR BETTER
54	.	OTHERS = OR BETTER

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